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BE IT KNOWN that I, Wesley N. Ludwig, have invented new and useful improvements in a

PERFORATING GUN WITH IMPROVED CARRIER STRIP

of which the following is a specification:

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PERFORATING GUN WITH IMPROVED CARRIER STRIP

Field of the Invention

This invention relates to a perforating gun for perforating a well, and to an improved carrier strip for carrying detonation charges to form perforations through which fluids are produced. More particularly, this invention relates to an improved carrier strip that resists separation upon firing of the gun.

Background of the Invention

In the recovery of well fluids, such as oil and gas, perforating charges are commonly mounted on a strip of metal and lowered into the well. When the charges reach a desired depth they are ignited to perforate the casing to enable or enhance production of oil or gas from the formation. The strips of metal are not reusable, so their entire cost contributes to the cost of the operation. To achieve a low cost, the strip is preferably made with as little material and as simply as possible. Examples of perforating guns and carrier strips for carrying perforation charges are disclosed in U.S. Patents 6,591,911, 6,216,596, 6,098, 707, 5,701,964, and 5,590,723.

Perforating charges typically are constructed of a shaped explosive in a sealed metal container or can that focuses the force of the explosion into a jet that forms a hole in the well casing and formation. The charges are designed so that the metal can eventually breaks into small pieces at the end of the firing process, after the perforation is formed. At some point in the

process, the metal can acts as a pressure vessel containing much of the force of the explosion and allowing the expanding gases to exit the can in a well defined jet through the portion of the can threaded into the carrier strip. When the metal can starts to break apart, it exerts large longitudinal or axial forces on the carrier strip, sometimes causing the mounting hole to elongate or even tear apart.

Existing carrier strips typically have larger, threaded holes to directly screw a charge container into the carrier strip, along with smaller holes axially spaced from the larger holes, which are used to mount brackets that position other charges at various angles relative to the face of the carrier strip. An example of this type of carrier is illustrated in U.S. Patent 6,591,911. The smaller mounting holes are spaced appreciably from the larger holes due to geometric constraints, such as the size of the charges, required room for bending of the primer cord, and room to mount brackets for any angled charges. The smaller holes are also generally desired to be sufficiently small not to weaken the strip.

The general goal of improving the durability of carrier strips has been addressed somewhat by U.S. Patent 6,098, 707. The '707 patent discloses a perforating gun comprising a charge receiving area of a strip having a greater width than intervening areas of the strip, to provide an increased support surface for charge units. Although this may provide enhanced durability, it is not optimal in terms of having both a simplified design and resistance to downhole separation. Existing carrier strips have not achieved a high level of simplicity and resistance to separation. Prior art carrier strips that separate laterally downhole upon firing of the

gun can be difficult and expensive to retrieve to the surface, and may prevent successful operation of other downhole equipment.

A perforating gun is therefore desired having an improved charge carrier strip that is relatively simple and inexpensive to manufacture, while having improved resistance to separation during firing.

Summary of the Invention

In one embodiment, a perforating gun including a plurality of charge containers are supported on an elongate carrier strip having a plurality of mounting holes, with each charge container being supported on the carrier strip through substantially continuous contact between the charge container and the mounting hole. A pair of webs is defined between each mounting hole and adjacent edges of the carrier strip. A relief hole is positioned longitudinally adjacent to each mounting hole, with the spacing between a perimeter of the relief hole and a perimeter of the mounting hole being less than each web width. As a result of this relief hole positioning, the carrier strip desirably provides less resistance to outward yielding of the charge container at a location adjacent the relief hole than at locations adjacent to the web. When the perforating gun is detonated, there is a significantly reduced likelihood of the elongate strip separating laterally, thereby avoiding problems with portions of the strip dropping in the hole and not being retrieved with upper portions of the elongate strip.

In some embodiments, the relief hole is longitudinally spaced from the mounting hole to form a deformable relief section which yields toward the relief hole in response to detonation of the charge carrier. The longitudinal spacing between a perimeter of the relief hole and a perimeter of the respective mounting hole may be less than 50% of either web width. Relief holes are preferably provided on longitudinally opposite sides of the mounting hole, and may have a circular or slot configuration. In other embodiments, a relief hole may alternatively intersect the mounting hole to further decrease resistence to outward yielding of the charge

container. A plurality of relief holes may also be provided on one or both sides of the mounting hole to further encourage longitudinal, rather than lateral, splitting of the carrier strip. The elongate strip is less likely to laterally separate upon firing of the gun due to the presence of the relief holes, even though each charge container is directly mounted to the carrier strip by a threaded connection. In alternate embodiments, the charge container may be pressed into a mounting hole in the carrier strip to provide the substantially continuous contact between an outer surface of the charge container and an inner surface of the mounting hole. The carrier strip may have a substantially uniform width between the opposing edges of the carrier strip, thereby allowing the carrier strip to be economically manufactured by an extruding operation.

In another embodiment, the perforating gun is similarly provided with an elongate carrier strip and a plurality of charge containers. Charge container brackets are mounted on the carrier strip in a conventional manner, with each bracket having laterally opposing edges and a charge container mounting hole defining a pair of webs between the mounting hole and the edges of the bracket. A relief hole is positioned in each bracket longitudinally adjacent a mounting hole , with a longitudinal spacing between a perimeter of the relief hole and a perimeter of the mounting hole being less than the web width. The relief hole or the plurality of the relief holes in each bracket include the same features and spacings as in embodiment having the relief hole in the carrier strip. By minimizing the likelihood of lateral separation of the brackets upon firing of the gun, portions of a bracket cannot pivot about the mounting holes, and thereby do not create hooks that may catch downhole equipment to make removal of the gun difficult.

A feature of the present invention is that the relief holes may be provided in the elongate strips or in the mounting brackets with a nominal increase of cost. A substantial advantage of the invention is the reduced likelihood of lateral separation of a perforating gun carrier strip or a mounting bracket upon firing of the gun, thereby reducing problems associated with retrieving portions of the perforating gun after firing or having portions of the gun interfere with other downhole equipment.

These and further features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

Brief Description of the Drawings

Figure 1 shows a conventional carrier strip for use in a perforating gun;

Figure 2 shows a charge container for use with the perforating gun;

Figure 3 show a portion of a preferred embodiment of an improved carrier strip according to the invention;

Figure 4 shows another preferred embodiment, wherein relief holes intersection the mounting holes;

Figure 5 shows an embodiment of the carrier strip wherein the relief holes are slot shaped;

Figure 6 shows an embodiment of the carrier strip having slot shaped relief holes, with inner ends that are substantially concentric with the mounting hole, resulting in a constant width relief section;

Figure 7 illustrates charge containers secured to the carrier strip, with slot shaped relief holes similar to those of Figure 6;

Figure 8 illustrates a cross-sectional view of the carrier taken along section line 1-1 of Figure 7, to show further details of one of the charge containers secured to the carrier strip;

Figure 9 shows a cross-sectional view taken along section line 2-2 of Figure 7, to show a section of the carrier strip without a charge container;

Figure 10 shows a perspective view of Figure 7;

Figure 11 illustrates a carrier strip having multiple relief holes longitudinally arranged on

each side of the mounting hole; and

Figure 12 shows a charge container mounted on a bracket, by substantially continuous contact between the charge container and a mounting hole through the bracket.

Figure 13 illustrates a charge container with its probable location of failure as mounted on a conventional carrier strip.

Detailed Description of the Preferred Embodiments

Figure 1 shows a typical conventional carrier strip 110 for use in a perforating gun. A strip centerline 113 may be defined as passing centrally through carrier strip 110 along its length, with respect to which other features may be described. The carrier strip 110 typically has a generally flattened cross-sectional shape, as shown in Figure 9. The carrier strip 110 may include bends, such as in a spiraling carrier strip (not shown), in which case the strip centerline 113 will not be straight, and instead may have a spiraling configuration. The carrier strip 110 has laterally opposing edges 124.

A plurality of charge containers 50, conceptually shown in Figure 2, may each be positioned within a respective charge container mounting hole 112 through carrier strip 110. The mounting holes 112 may either provide mere clearance for insertion of the charge containers 50, in which case a bracket or other support member (discussed below in connection with Figure 12) may be used to secure the charge container 50 to the strip, or the charge containers may be secured directly to the mounting holes 112, such as with threads 30. The charge container 50 has a first section 41, which typically is packed with charge material, and a second section 40 press fit to section 41 to enclose the charge material. A primer cord for detonating the charge container 50 may be secured at location 152.

Referring still to Figure 1, a pair of longitudinally extending webs 118 are defined between the laterally opposing edges 124 and each mounting hole 112. Other holes 126 are optionally provided as shown, such as for securing additional brackets carrying additional charge

containers. The other holes 126, however, are spaced a considerable distance from the mounting holes 112, leaving a large section 109 of strip material between each mounting hole 112 and other holes 126. The spacing of the mounting holes, 112 is determined by the spacing of the charges, and is sufficiently large to accommodate the maximum diameter of the charges and the bend radius of the primer cord.

When a charge container 50 is detonated on such a conventional carrier strip 110, the carrier strip 110 has a tendency to fail, typically severing the carrier strip 112 into multiple pieces that are difficult to retrieve from a well. When a charge container is directly supported from a carrier strip through substantially continuous contact with the inner wall of the mounting hole (rather than merely passing through a hole and being supported by a bracket), the failure mechanism of a conventional perforating gun carrier strip 110 can be simplified by a two step failure model. In the first step, as the charge container 50 starts to expand and before it breaks apart or shatters, pressure is distributed relatively uniform around the perimeter of the mounting hole 112. The carrier strip 110 will respond by deforming. The carrier strip 110 is naturally most easily deformed by the expansion force in the area of the relatively thin webs 118 of material defined between the larger mounting holes 112 and the outer edges 124 of the carrier strip 110 than at the relative large section 109 of strip material between each mounting hole 112 and other holes 126. The increased stress causes the charge container 50 to crack at or near the webs 118, preferentially transverse to the centerline 113 of the carrier strip 110. Figure 13 shows this probable line of failure 111 on a charge container 50 positioned on the strip 110. The line of

failure 111 is shown adjacent to webs 118. In the second step, once the container 50 has separated into substantially two halves, 150, 151, the internal pressure then separates the halves 150, 151 of the charge container parallel to the centerline of the strip, generally resulting in a net axial force elongating the mounting hole 112 along the centerline 113 of the carrier strip 110. If the metal yields too much before the energy of the charge is dissipated, the carrier strip 110 will be broken transverse to the longitudinal axis, and a lower broken portion of the carrier strip 110 will then be more difficult to retrieve downhole.

Figure 3 shows a portion of a preferred embodiment of an improved carrier strip 10 according to the invention, in contrast to the conventional carrier strip 110 shown in Figure 1. A centerline 13 may be defined as passing centrally through carrier strip 10 along its length, with respect to which other features may be described, similar to the centerline 113 of Fig. 1. The carrier strip 10 also typically has a generally flattened cross-sectional shape, as shown in Figure 9. The carrier strip 10 may also include bends, such as in a spiraling carrier strip (not shown), in which case the centerline 13 need not be straight. The spiraling configuration may be helical shape, or a regular octagonal spiraling pattern,. The carrier strip 10 may also have straight sections that are twisted about the centerline 13 at selected locations, to orient charge containers at different firing positions. The carrier strip 10 has laterally opposing edges 24, so that the carrier strip has a uniform width extending longitudinally. A plurality of charge containers 50 (as in Fig. 2) may be positioned within respective charge container mounting holes 12 through carrier strip 10.

Referring again to Figure 3, the mounting holes 12 should provide substantially continuous contact between an outer surface 31 of the charge container 50 and an inner surface 22 of the mounting hole 12, to secure the charge container 50 to the carrier strip 10. The charge containers 50 are preferably secured directly to the mounting holes 12, such as with a threaded connection between threads 30 on the charge container and threads 33 on the inner surface 22 of the mounting hole 12. Alternatively, the charge containers 50 may be press fit into a mounting hole 12 to directly support the charge container 50 by providing the substantially continuous contact between the outer surface 31 and inner surface 22. A pair of longitudinally extending webs 18 are defined between the laterally opposing edges 24 and each mounting hole 12. Other holes 26 are still optionally provided as shown, such as for securing additional brackets carrying additional charge containers 50.

One or more relief holes 14 are also included with the carrier strip 10, however, which typically have relatively large diameters and are positioned more closely to the mounting holes 12. The carrier strip 10 in Figure 3 therefore has a relatively narrow section 16 of strip material between each mounting hole 12 and respective relief hole 14. This narrow section 16 may be referred to as a relief section 16. Because there is substantially continuous contact between an outer surface 31 of the charge container 50 and an inner surface 22 of the mounting hole 12, the charge container 50 when detonated will attempt to expand uniformly outwardly against the mounting hole 12. The relief section 16 will provide significantly less resistance to outward yielding of the charge container 50 than either of the webs 18, because the relief section 16 has

less material than the webs 18. In contrast to the failure mode of conventional strips described in connection with Figure 1, the charge container 50 will instead preferentially split at a location adjacent each relief hole 14, at relief section 16 along a probable line of failure 11, as shown in Figure 8. If the charge container 50 then separates into substantially two halves, it will exert a transversely outward force on the respective mounting hole 12, in which case the carrier strip is less likely to be forcibly separated into two or more pieces. Even if the carrier strip 10 does split, it will more likely split in the direction of the longitudinal centerline 13, such as partially splitting along the centerline 13 at relief section 16.

The substantially continuous contact between an outer surface 31 of the charge container 50 and an inner surface 22 of the mounting hole 12 is very important. That contact supports the charge container 50 so that it preferentially yields at locations adjacent to the relief holes 14, rather than unpredictable at some arbitrary other location. This substantially continuous contact may be provided by either the press fit connection or threaded connection between the charge container 50 and mounting holes 14, as described above. The substantially continuous contact is not provided, however, in certain prior art embodiments, such as those carrier strips discussed above having mere loosely fitting clearance holes, and whereby the charge containers are secured by brackets. Some minor clearance may be possible with the present invention, but it would be less than the amount of expansion the charge container would endure prior to yielding. Typically, any such clearance would need to be less than one or two thousandths of an inch between the charge container and mounting hole.

The relief section 16 should provide less resistance to yielding than the webs 18, to achieve the results intended. In embodiments where the relief hole 14 has a relatively large diameter and is extremely close to the mounting hole 12, it can be reasonably concluded upon visual inspection that the relief section 16 should provide less resistance to yielding than the webs 18, according to the invention. Due to a number of variables affecting yield resistance, however, such as the distance between a relief hole 14 and a mounting hole 12, and the diameter of the relief hole 12, it is desirable to construct a carrier strip 10 according to certain predefined parameters. At a minimum, a spacing between the perimeter of each relief hole and the perimeter of respective mounting hole should be less than the width of either web 18. In preferred embodiments, this spacing is less than 50% and preferably less than 25% of a width of either web 18. Additionally, the diameter of the relief hole 14 is preferably greater than 50% of the diameter of the respective mounting hole, and in more preferred embodiments is about 70% of the diameter of the respective mounting hole.

For example, in a carrier strip having a width of 1.146 inches, a mounting hole having a diameter of .625 inches, spaced a center-to-center distance of .562 inches from a relief hole having a diameter of .438 inches would result in a spacing of approximately .031 inches between perimeters of the mounting hole and relief hole (i.e. the narrowest width of the relief section 16 would be .031 inches). Each web width would be .260 inches. Thus, the diameter of the relief hole 14 would be slightly more than 70% of the diameter of the mounting hole 12, and the spacing between the perimeters of each relief hole and respective mounting hole is less than

12%.

In other preferred embodiments, as illustrated in Figure 4, the relief hole 14 may be positioned so closely to the mounting hole 12 that the two holes 12, 14 intersect. The inner surface 22 of the mounting hole 12 thus sufficiently extends circumferentially to support the charge container 50 with substantially continuous contact between the inner surface 22 of the mounting hole 12 and an outer surface 31 of the charge container 50. In contrast to the embodiment of Figure 3, however, there is an opening in the surface 22 at intersection 17. Because there is no relief section, there is little or no resistance to outward yielding of the charge container 50 adjacent the relief hole 12, as compared with locations adjacent the webs 18. As with the embodiment of Figure 3 having the relief section 16, the embodiment of Figure 4 will thus allow the charge container 50 to preferentially fail along a generally longitudinal break line.

The relief holes are preferably circular, as in Figure 3, because a circular shape is generally least expensive to manufacture. For example, the relief holes may be manufactured by stamping the carrier strip with a circular die, or by passing a rotating machine bit through the carrier strip 10. In other embodiments, however, the relief holes need not be circular. Figures 5 and 6 illustrate embodiments of the carrier strip 10 in which the relief holes are slots 14. As in Figure 3, the relief holes or slots 14 shown do not intersect the mounting hole 12, although in other embodiments they might. Instead, a relief section 16 again bridges the mounting hole 12 and relief holes 14, to deform more readily than the webs 18. The slots 14 in Figure 5 have semi-circular ends 17, such as might be created using a circular-profile bit during a milling operation.

The slots 14 in Figure 6 instead include curved inner ends 19 that are substantially concentric with the mounting hole 12, resulting in a constant width relief section 16 that is possibly easier to yield. Other potential ways of making the relief holes include laser cutting and water-jet cutting

Figure 7 illustrates charge containers 50 secured to the carrier strip 10 and having substantially continuous contact with the mounting hole 12. The carrier strip 10 shown happens to have slot-shaped relief holes 14, although the choice of relief hole shape generally does not affect how charge containers 50 are inserted and secured to the mounting hole 12, i.e., the relief holes 14 could have any shape within the guidelines set forth above. The relief holes 14 could even intersect the mounting hole 12 as described in conjunction with the embodiment of Figure 4, provided there were sufficient threads 33 on the inner surface 22 of the mounting holes 12 in Figure 4 to secure the charge containers 50, via threads 30.

Figure 8 illustrates a cross-sectional view taken along section line 1-1 of Figure 7, to show further details of one of the charge containers 50 secured to the carrier strip 10 with threads 30. The section view shows the generally flattened shape of the carrier strip 10. Webs 16 are also visible. Figure 9 shows a cross-sectional view taken along section line 2-2 of Figure 7, to show a section of the carrier strip 10 without a charge container 50. Figure 10 show a perspective view of Figure 7, where again the relief holes 14 are shown as slots, but may have other shapes.

In some embodiments, a plurality of relief holes may be longitudinally arranged to one side of a respective mounting hole with a longitudinal spacing between the perimeter of any two

relief holes being less than 25% of either web width. Figure 11 illustrates a carrier strip 10 having 2 relief holes 14, 15 longitudinally arranged on each side of the mounting hole 12. Relief sections 16 are provided for the same purpose as in other embodiments. Although strip material at locations 21 are similar in appearance to relief sections 16, they have much less influence on yielding of the charge container 50 than do the relief sections 16. Instead, the purpose of additional relief holes are to promote preferential failure in a direction generally along centerline 13. If the charge container 50 desirably separates into substantially two halves near the relief sections 16, the two halves will tend to pull the strip 10 laterally apart. The additional relief holes 15 thus allow greater yielding and energy absorption along the centerline 13.

As mentioned above, the invention may also be applied to a perforating gun in which a bracket or other support member is used to secure the charge container 50 to the strip. Figure 12 shows a charge container 50 mounted in such a bracket 220, by substantially continuous contact between the charge container 50 and a mounting hole 212 through the bracket 220. Relief holes 214 are shown spaced slightly from the mounting hole to define relief sections 216, although in some embodiments the relief holes 214 may intersect with the mounting hole 212 as described in connection with other embodiments. Instead of the charge container 50 being directly supported on the carrier strip discussed above, the bracket 220 is instead secured to the carrier strip, such as with bracket mounting members passing through mounting holes 210, which align with holes 26. When charges are mounted on the brackets, separation of the carrier strip during detonation of the charge containers 50 is generally not the primary concern. Instead, the invention helps ensure

the bracket 210 does not fail in a transverse direction at webs 218 between the mounting hole 212 and bracket edges 224. If the bracket 220 were to fail, pieces of the bracket 220 that remain attached to the carrier strip might pivot, creating hooks that could catch on downhole equipment and make removal of the perforating gun difficult. As before, the spacing between perimeters of the relief holes 214 and the mounting hole 212 is less than the spacing between bracket edges 224, and the mounting hole 212, i.e., less than a width of webs 218, to provide less resistance to yielding at locations adjacent the relief holes 214 than locations adjacent the webs 218.

While preferred embodiments of the present invention have been illustrated in detail, modifications and adaptations of the preferred embodiments may occur to those skilled in the art. It is to be expressly understood, however, that such modifications and adaptations are within the scope of the present invention as set forth in the following claims.